



# NASA's Plum Brook Station Water Systems

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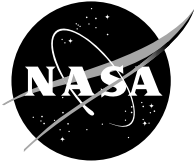
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This work was sponsored by the Low Emissions Alternative  
Power Project of the Vehicle Systems Program at the  
NASA Glenn Research Center.

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## **Summary**

Plum Brook Station's water systems were built in the 1940s to support a World War II ordnance production complex. Because the systems had not been analyzed for current NASA usage, it was unknown if they could meet current requirements and codes or if they were efficient for current use. NASA wanted to determine what improvements would be needed or advisable to support its research projects, so it contracted a hydraulic analysis of the raw and domestic water systems. Burgess and Niple determined current water demands and water flow, developed and calibrated models of the two water systems, and evaluated efficiency improvements and cost-cutting options. They recommended replacing some water mains, installing a new service connection, and removing some high-maintenance items (an underground reservoir, some booster pumps, and a tower).

## **History**

Plum Brook Station is a 6400-acre Government-owned complex, a field station of the NASA Glenn Research Center in Cleveland, Ohio. Located in north central Ohio near Lake Erie in Sandusky (approximately 50 mi west of Cleveland), this NASA field station performs complex and innovative ground tests for the U.S. Government (civilian and military), the international aerospace community, as well as other areas of the private sector (see figs. 1, 2, and 3).

Plans for Plum Brook began in January 1941 when the U.S. Army needed to produce nitroaromatic explosives in support of World War II efforts. It was originally called Plum Brook Ordnance Works (PBOW). Construction of the facilities began in April 1941, with the production of explosives starting in November 1941.

There were many logistical challenges during the buildup phase of PBOW. One was to provide the entire infrastructure needed to meet the needs of a manufacturing facility. Because of PBOW's rural location, the local utility companies could not supply these needs. Consequently, a utility infrastructure had to be built, including power and power distribution systems, sewer piping and treatment systems, and water distribution systems. This entire effort was a true "green field" exercise because the property secured by the Federal Government was farmland.

Coal-fired power plants and substations were constructed onsite, and power was distributed within a separate PBOW grid. A raw water system (untreated), for cooling processes as well as fire protection, was installed using water pumped directly from Lake Erie via two pumping stations, each located approximately 5 mi from PBOW. Domestic (treated) water was supplied by Erie County but was not adequate to meet all the water demands. Consequently, a 500 000-gal reservoir, along with six water towers (with a total capacity of 600 000 gal), and a distribution system of 40 mi of pipe were built.

By September 1941, a small municipal-sized infrastructure was built to support over 4000 people working in 700 buildings on 10 000 acres (fig. 4). Over 1 billion lb of ordnance were manufactured at PBOW from November 1941 through August 1945.

PBOW was closed in 1946 after the war ended, and the area remained in the custody of the Federal Government until the late 1950s. At that time, NASA began utilizing the land to support the U.S. space effort, and it became known as Plum Brook Station. Many test sites were built for research projects that required large, safe areas for dangerous tests. The large infrastructure was still in place from the PBOW era, and it was used, with minor modifications, to meet the different research project demands.

The existing utility infrastructure includes several improvements. Power is now supplied by the local utility company, and sewage is treated by a publicly owned treatment facility. However, the water system still operates as it did back in the 1940s, except some water towers have been eliminated and half of the piping system has been abandoned. Finished water is received via the Erie County Department of Environmental Services (ECDOES). The water flows into a 500 000-gal underground reservoir and is pumped by one of two 50-hp, 700-gal/min, 240-ft total dynamic head (TDH) pumps in the reservoir building directly to a 100 000-gal elevated water storage tank (Tower 1, see fig. 5). This maintains a system pressure between 60 and 70 psig for the north and central areas of Plum Brook Station. Excluding fire hydrant water, this tank provides all finished water for domestic use and building sprinkler systems. There is a bypass system around the reservoir; however, it is not sufficient to maintain the pressure within the Plum Brook Station distribution system and cannot fill Tower 1.

On the south end of the facility, finished water from the underground reservoir supplies another elevated tower (Tower 2). However, Tower 2 is filled by one of two 125-gal/min, 205-ft TDH dedicated pumps located at its base. Tower 2 is a 150 000-gal elevated water storage tank and has a higher overflow elevation than the 100 000-gal Tower 1. This tank is designed to provide the Space Power Facility with 60 000 gal of finished water for domestic use and 90 000 gal for building sprinkler systems and fire protection.

Raw water for fire hydrants and process water is pumped from Lake Erie from either the Rye Beach Pumping Station or the Big Island Pumping Station. These pumping stations currently have a pumping capacity of 11 650 and 1450 gal/min, respectively, at 100-ft TDH. The water is pumped into one of two reservoirs at Plum Brook Station. Reservoir 1 has a capacity of 5 500 000 gal, and reservoir 2 has a capacity of 6 000 000 gal. Water is pumped by one of two 700-gal/min 180-ft TDH electric pumps into a 150 000-gal elevated water storage tank (Tower 3, see fig. 6). Tower 3 provides process and fire-protection water for the north and central areas of Plum Brook Station.

The raw water and domestic water system have separate distribution piping and are not cross-tied. The domestic-water-distribution piping system consists of approximately 81 000 ft of pipe ranging in diameter from 3 to 16 in. The raw-water-distribution piping system consists of approximately 200 000 ft of pipe, ranging in diameter from 4 to 18 in.

Because neither of the systems had been fully analyzed, it was unknown whether or not they could meet current requirements and codes. Also, since the systems had been built to accommodate the large demands of the ordnance plant, they probably were no longer operating efficiently. With the maintenance as well as the operating costs of the 1940s equipment increasing, NASA wanted to embark on a multiyear project to make improvements to these systems. The following questions needed to be studied before the construction design work could begin.

### **Raw Water System**

- (1) Can the system provide the current operational demands?
  - (a) Can it supply the required fire pressures and flows?
  - (b) Can it provide the required design pressures and flows to be used as an emergency water supply at one of the facilities it supplies?
- (2) What can be done to optimize the operation of this system?

## **Domestic Water System**

- (1) Can the system provide the current operational demands?
  - (a) Can it supply the proper sprinkler design pressures and flows?
  - (b) Can it meet the design demands while operating a process steam plant and still maintain pressure and flow at the other facilities it supplies?
- (2) What can be done to optimize the operation of this system?

These questions prompted the need for a hydraulic analysis of the current water distribution system. NASA contracted Burgess & Niple (B&N) to perform this work and to provide recommendations for meeting NASA's objectives.

## **Model Creation, Data Collection, and Calibration**

B&N used WaterCad Version 4.5, developed by Haested Methods, for the models and analysis. For the model development, B&N obtained physical data such as the pipe size, length, the location and capacity for all elevated tanks, the location and pumping capacity of pump stations, and the location and functional description of control valves. Next, B&N determined the current water demands.

## **Raw Water System**

To determine the average and peak daily demands on the raw system, B&N used a list of the equipment using raw water at every facility along with typical demands. The average demand was determined to be 186 gal/min. By utilizing the data collected at the tower pumps, B&N determined a peak factor of 2.0, yielding a peak flow of 372 gal/min.

All the fire hydrants at Plum Brook Station are connected to the raw water system; therefore, the system fire demands were analyzed using the flow rates and pressures required by the National Fire Protection Association (NFPA).

In addition, NASA utilizes this system as emergency cooling at its Hypersonic Tunnel Facility, the largest "clean air" hypersonic tunnel facility in the world. The facility can produce a synthetic air jet stream that travels in excess of 5 times the speed of sound at 1000 psig and 3900 °R. High temperatures are created using a 3.5-MW induction storage heater. At this temperature, the heater mass contains approximately 130 million Btu. In the event of a failure, the heater is designed such that the raw water system must provide emergency backup flow of 945 gal/min at 60 psi for a minimum of 48 hr to keep the heater from disintegrating.

## **Domestic Water System**

Plum Brook Station meters the domestic water from ECDOES as it enters the 500 000-gal reservoir. For determining the average and peak daily demands of the domestic system, B&N averaged water records over the last 3 yr and divided usage between the different facilities on the basis of Plum Brook Station's water distribution diagram. The average daily flow of the entire Plum Brook Station is 42 392 gal/day, and the maximum daily flow is 132 311 gal/day, or 3.12 times the average daily flow.

The domestic water distribution only services fire sprinkler systems in four of the existing facilities; however, fire sprinkler systems are currently being installed in two future facilities, and those facilities also were included in the analysis. Table I lists the facilities, the flow required, and the residual pressure required, which is the minimum pressure necessary to provide the desired flow at the location of

the required flow. These flow rates and residual pressures were used in the analyses of the fire flow capability.

TABLE I.—SPRINKLER SYSTEM REQUIREMENTS

Facility	Flow required, gal/min	Residual pressure required, psi
Space Power Facility	250	35
Engineering building	320	53
Garage	250	35
Shipping and receiving	250	35
Future cryogenic laboratory 1	250	35
Future cryogenic laboratory 2	333	35

In addition, NASA utilizes the domestic system to supply water to its process steam plant. The plant consists of three boilers—two rated at 28 000 lb/hr and one at 1700 lb/hr—for a total draw of 230 gal/min. The two larger boilers produce steam that is stored in a bank of five accumulators, which store approximately 500 000 lbm of supersaturated steam. This stored steam is used as the motive fluid for the ejector systems that create the vacuum conditions at two of the four operating NASA test facilities. Flowing 660 lb/sec of steam at 150 psig simulates altitude conditions in excess of 100 000 ft in the test sections. During operation, the ejector can be heard up to 10 mi away (see fig. 7).

After the physical and design data were collected on both systems, B&N performed flow tests to collect the actual flow data needed to calibrate both of the models. B&N performed a sensitivity analysis on the water model to determine how sensitive the model was to variations in demand allocations and pipe C-factors. The final C-values used were based on the flow-testing results versus model results, coupled with engineering judgment.

Once the models were calibrated, B&N could run multiple scenarios for both the domestic and raw systems and could analyze the systems to meet NASA objectives.

## Operational Findings and Recommendations

The final results from the B&N study of the current operation of the systems follow.

### Raw Water System

The calibrated model predicted that the system could handle the average, peak, and fire flow demands, as well as the emergency cooling condition needed by the Hypersonic Tunnel Facility heater. So it was determined that no functional improvements were needed to this system.

### Domestic Water System

The calibrated model predicted that the system could handle the average and the peak demands. However, it also predicted that the system has some operational and sprinkler flow deficiencies.

(1) With the exception of the Space Power Facility, which has a dedicated elevated tank (Tower 2), the domestic system cannot supply the required sprinkler system flow and residual pressure to the

engineering building, the garage, shipping and receiving, and the future cryogenic compound laboratory buildings.

(2) When the process steam plant was operating, the facilities adjacent to that facility had inadequate pressures according to the applicable codes.

System dynamics needed to be improved to meet these deficiencies, and it was obvious that the least expensive method to correct this problem was the replacement of selected mains with larger diameter pipes, in conjunction with making some flow loops. B&N ran multiple flow scenarios within the model and provided the following recommendations to best solve the resulting deficiencies:

(1) To improve the sprinkler deficiency, replace 10 000 ft of 3-, 4-, and 6-in.-diameter water main with a new 8-in.-diameter water main at an estimated cost of \$340 000.

(2) To improve inadequate pressures, construct 4900 ft of new 6-in.-diameter water main to loop at an estimated cost of \$110 000.

## **Optimization**

As stated earlier, once the improvements needed to handle the operational and fire demands were determined, the next step was to evaluate operating and maintenance cost-cutting options. NASA and B&N reviewed the operation of both systems and both agreed upon optimizations for each system. Each of these needed to be evaluated for the impact that it would have on the hydraulics of the system, as follows.

### **Raw Water System**

- Eliminate the entire system and utilize the domestic system.

### **Domestic Water System**

- Eliminate the 500 000-gal reservoir, domestic water pump house, and Tower 1.
- Eliminate Tower 2.

## **Optimizational Findings and Recommendations**

### **Raw Water System**

Completely eliminating the raw water system and converting it to a domestic system was determined to be impractical for several reasons.

(1) Many new water lines would have to be constructed for fire protection because of the small size of many of the existing domestic water mains.

(2) The cost to clean and inspect the existing raw water mains to convert them to domestic water mains would be prohibitive because they are infested with Lake Erie zebra mussels.

(3) The volume of water needed at the Hypersonic Tunnel Facility could not be provided by ECDOES, requiring NASA to construct additional water tanks.

(4) The cost to purchase finished water from ECDOES to convert the raw water system would be over \$130 000/yr using 2002 water rates provided by ECDOES.

Therefore, a decision was made to leave the raw water system in place but to add a few new mains to complete the looping of the system.

## **Domestic Water System**

The first step was to evaluate the effects of eliminating the 500 000-gal reservoir, pumps, and Tower 1. Two options were considered. Because Erie County recently replaced its water main near the current service connection from a 4- and 6-in. water main pipe loop to a 14-in. main, the first option was to build a new pump station at the same location as the existing pump station only with a larger diameter service connection. The new pump station could pull suction directly off of the ECDOES water main. However, this option was not feasible because these pumps would need to have a pumping capacity equal to the current pumps. In addition, variable-speed pumps would have to be used because if the water tower was eliminated, the system would have to perform in a more dynamic manner. Moreover, because of fire-protection requirements, the pumps would require a backup generator in the event of a power failure and would have to undergo more stringent NFPA testing requirements.

The second option provided a more economical choice. Because the ECDOES water system has expanded to meet the population growth of Erie County, a new location for the service entrance was evaluated. It was found that ECDOES has a 16-in.-diameter water main adjacent to Plum Brook that is on a higher hydraulic grade than the current service connection. The current connection is served from the ECDOES 1.0-million-gal elevated water tank with an overflow elevation of 767.50 ft. The new connection could be served from the ECDOES 0.75-million-gal elevated water tank with an overflow elevation of 815.00 ft. Because this elevation is higher than Tower 1, this tower could be eliminated. By installing a new service connection to the ECDOES water main adjacent to Plum Brook (including 7700 ft of 12-in.-diameter water main) and by abandoning Tower 1, the 500 000-gal reservoir, and the pump station, NASA would realize a favorable 9-yr payback.

The next item evaluated was the elimination of Tower 2 and its pump station at the southern end of the facility. Because of the length of the new water main, the best option was to provide a new tie into the ECDOES system at the southern end. A new 12-in.-diameter main would then be constructed from this new connection to the existing distribution system. This option would provide NASA with two connections to the ECDOES system and would allow for greater future capacity into NASA's Plum Brook Station.

However, when the maintenance and operating costs of Tower 2 were compared with the installation of a new service connection at the southern end of the facility, the payback was determined to be 26 yr.

## **Conclusions**

The analysis of both water systems gave NASA solid engineering rational for a capital improvement project. It gave sound engineering justification for the needed improvements and changes to the system:

1. Identified operational deficiencies and recommended improvements
2. Recommended removing high operational and maintenance items (the underground reservoir, the booster pumps, and Tower 1) by installing a new service connection
3. Recommended leaving Tower 2 in place, with the stipulation that NASA continually review the long-term costs associated with this tower
4. Recommended improvements to how NASA makes use of the assets provided by ECDOES



Figure 1.—European Space Agency's Ariane 5 payload fairing in Plum Brook Station's Space Power Facility for vacuum jettison testing.



Figure 2.—Boeing's Delta 3 upper-stage test at Plum Brook Station's B-2 facility.



Figure 3.—Boeing's hydrogen-mitigation test at Plum Brook Station's K-Site facility.



Figure 4.—Plum Brook Ordnance Works, circa 1944. Tower 1, a Pittsburgh DesMoines 100 000-gal-capacity domestic water tower with riveted construction, is shown in the center of the photograph.



**Figure 5.—Domestic water Tower 1, as it looks today. It is still in operation.**



**Figure 6.—Raw water Tower 3, as it looks today. Originally a Plum Brook Ordnance Works tower, Tower 3 is a Pittsburgh DesMoines 150 000-gal-capacity water tower with riveted construction. It is still in operation.**



Figure 7.—Steam ejector in operation at Plum Brook Station's Hypersonic Tunnel Facility.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE July 2006		3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE  NASA's Plum Brook Station Water Systems			5. FUNDING NUMBERS  100000236, Line 10	
6. AUTHOR(S)  Robert M. Puzak and Arthur Kimpton				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191			8. PERFORMING ORGANIZATION REPORT NUMBER  E-14716	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA TM-2006-213208	
11. SUPPLEMENTARY NOTES  Robert M. Puzak, Plum Brook Station, Sandusky, Ohio 44870; and Arthur Kimpton, Burgess & Niple, 100 West Erie Street, Painesville, Ohio 44077. Responsible person, Robert M. Puzak, organization code DC, 419-621-3204.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified - Unlimited Subject Category: 31  Available electronically at <a href="http://gltrs.grc.nasa.gov">http://gltrs.grc.nasa.gov</a> This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  Plum Brook Station's water systems were built in the 1940s to support a World War II ordnance production complex. Because the systems had not been analyzed for current NASA usage, it was unknown if they could meet current requirements and codes or if they were efficient for current use. NASA wanted to determine what improvements would be needed or advisable to support its research projects, so it contracted a hydraulic analysis of the raw and domestic water systems. Burgess and Niple determined current water demands and water flow, developed and calibrated models of the two water systems, and evaluated efficiency improvements and cost-cutting options. They recommended replacing some water mains, installing a new service connection, and removing some high-maintenance items (an underground reservoir, some booster pumps, and a tower).				
14. SUBJECT TERMS  Water management			15. NUMBER OF PAGES 16	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	20. LIMITATION OF ABSTRACT	



